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CW Operation of LSA Oscillator Diodes—44 to 88 GHz

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Bulk n-GaAs oscillator diodes have been operated on a continuous basis in the LSA (Limited Space-charge Accumulation) mode[1] at frequencies from 44 to 88 GHz. This is the first time a practical solid-state oscillator has operated continuously in this high-frequency range. The reason the LSA diode can produce millimeter wave power at higher frequencies than other solid-state devices such as transistors, tunnel diodes, IMPATT diodes, and Gunn diodes is because it is the first device which is not subject to the "transit-time limitation."

The "transit-time limitation" exists for these other devices because they must be designed so that the time required for a charge carrier to move from the source contact to the drain contact must be shorter than or on the order of one RF cycle. A common principle of all these devices is the bunching of space charge which remains until it drifts into a contact. Since carriers in semiconductors such as silicon, germanium, and gallium arsenide have maximum drift velocities on the order of 10^7 cm/sec, devices for higher frequencies must be designed with proportionally thinner active regions. The power and impedance of such a device both decrease proportionally to the thickness of the active region, so the maximum value of the product of power and impedance decreases as the square of the thickness or as the reciprocal of the square of the frequency, f. The lowest impedance which is practical increases with frequency at microwave frequencies because of skin effect. The result of all these considerations is that the transit-time limitation causes the maximum power of a given device to decrease faster than f^{-2} as f increases.[2,3]

The LSA diode is not subject to the transit-time limitation because it derives its ability to transform dc to ac directly from the negative differential of drift velocity of the individual electrons with respect to electric field[4,5] rather than to the movement of space charge across the device. There are two main requirements for preventing space charge from accumulating and distorting the electric field which would lead to Gunn oscillations at a lower frequency: The ratio of doping to frequency must be within a certain range, which for n-GaAs appears to be 10^4 to 2×10^5 sec/cm^3. Also, the resonant circuit must be properly loaded so that the electric field swings into the positive conductance region below 3000 V/cm for part of each cycle to quench out any space charge which has started to accumulate.[1]

The existence of the LSA mode was first verified on a pulse basis at 1, 10, and 30 GHz, then the experimental effort was directed toward producing a 50-GHz CW oscillator. In interpretation of the results shown in Table I and Fig. 1, it should be kept in mind that these are only preliminary results. In particular, no attempt was made to obtain high pulse powers, the pulse powers reported are from the same devices that operated CW at lower voltages and much lower efficiencies.

Table I gives the results obtained from the first diodes that operated on a continuous basis. All of these devices were made from a wafer of epitaxially grown n-GaAs with a carrier density of about 8×10^{15} cm^{-3}. The active region was 5 microns thick, and the current maximum occurred at 2 volts. Noise due to the diodes could not be detected on the HP-851A spectrum analyzer, indicating the carrier-to-noise ratio was

TABLE I—LSA DIODE EXPERIMENTAL RESULTS

Diode	Voltage (V)	RF Power (mW)	Frequency GHz	Efficiency (%)
Continuous				
D1	3.5	20	84–88	2.0
D2	3.6	15	51	0.7
D3	3.3	20	44–51	0.7
		(40*)		(1.4)
Pulsed				
D1	5.0	50	84	4.0
D2	7.0	400	51	9.0
D3	11.0	500	44–51	3.0
		(700*)		(4.0)

* Holder cooled with dry ice.

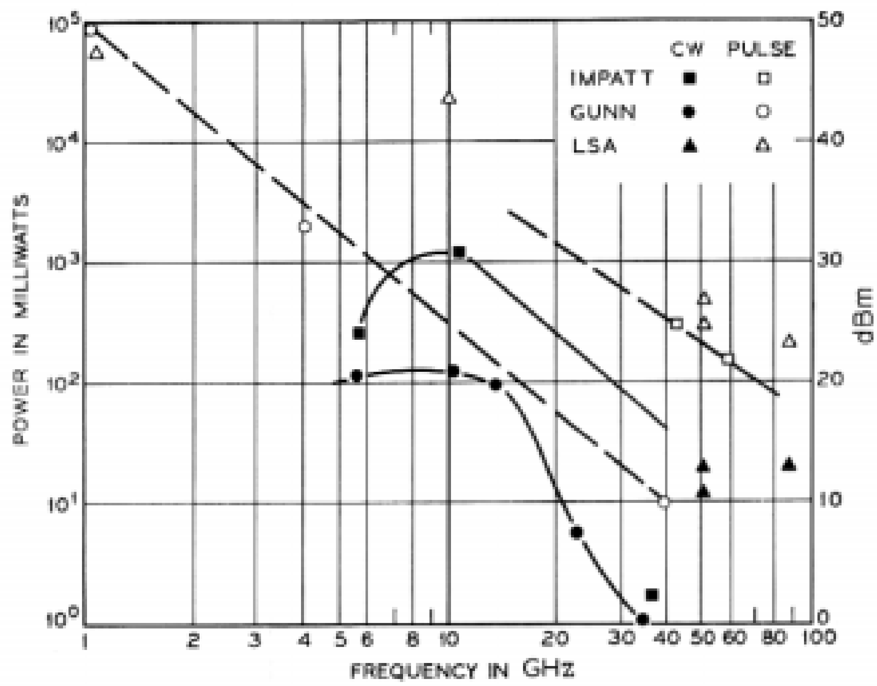

Fig. 1 — Power obtained from three types of solid-state oscillator diodes vs frequency as found in the literature. The LSA points were all obtained at Bell Telephone Laboratories except for the 10-GHz pulse result (Ref. 8).

greater than 90 dB in a one-cycle bandwidth one MHz from the carrier. Similar operation was obtained on a pulse basis at four times higher voltage with material with a 20-micron active region; however, heat problems prohibited CW operation of these samples.

Heating limits the CW efficiency of the diodes by restricting the bias voltage and by causing the carrier velocity as a function of electric field to become less favorable. The heating problem can be alleviated in the future for this device configuration by using a lower carrier density, by using smaller areas, and by making the substrate and liquid-regrowth contacts thinner. Details on the circuit used will be presented in Ref. 6.

In order to fully utilize the LSA mode of oscillation, a radical change in device design is needed. The devices reported on here were originally designed to be used as Gunn diodes at lower frequencies, from 5 to 20 GHz and are thinnest in the direction parallel to the current.[7] In order to increase the power and operate CW at lower frequencies, future LSA oscillator diodes should be long in the direction parallel to the current and thin in a direction perpendicular to the current. The heat will be removed from the sides and the thin dimension perpendicular to the electric field will eliminate skin effect problems.

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